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Fifty Years of Grassland Science Leading to Change

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ABSTRACT

Division C-6 was established in 2000, but members associated with forages and grazinglands have been active in the Crop Science Society of America (CSSA) since its inception; 21 have served as President and many authored textbooks and comprehensive reference works. Complex forage and pasture mixtures were common in 1955, but shifted to monocultures in the 1960s and 1970s. Mixtures returned in the 1980s as N prices increased, broader values of legumes became known, nutritive value was better understood, and environmental issues increased. Alfalfa (*Medicago sativa* L.) for dairy production had strong leadership from the private sector in seed production and breeding. Tall fescue (*Festuca arundinacea* Schreb.) was well-adapted, conserved soil, and extended grazing in the transition zone to increase beef cow–calf production. Bermudagrass [*Cynodon dactylon* (L.) Pers.] benefited from vegetative propagation, conserved soil, and was improved for adaptation, yield, and nutritive value. Yield advancements, except for a few species, have been discouraging. Management benefited from advances in disease resistance, methods for assessing nutritive value, and understanding the role of endophytic fungi. Modest increases in nutritive value, coupled with improved pasture management, have increased animal performance. Emerging interests include biomass, carbon sequestration, and roles of biodiversity. Molecular techniques offer potential to better understand the plants and make genetic progress.

For centuries, livestock have been considered a symbol of riches in many cultures, even when livestock were generally raised on native grassland and forested areas. Grassland science had its beginnings several centuries ago when early civilizations began to understand the principles of management of the native species in the areas they occupied. Early civilizations adapted this practice and later the concept spread with the migration of peoples from Mesopotamia into Africa, Asia, and Europe. Nomadic agriculture epitomized this situation and likely brought forward some concepts about rotational grazing and the value of yield, nutritive value, and persistence of forage and grassland species to the cultural system. The American Indians valued grasslands and prairies as areas for bison (*Bison bison* L.) and other ungulates that served as food sources. They knew the importance of rest periods and grazing pressure, and even learned to burn strategic areas to stimulate the growth of grasses and to encourage grazing migrations.

Harvested forage was a more recent phenomenon; one that arose when people settled in one place, often to cultivate and farm the land. They needed supplies of forage for their ruminant livestock and draft animals during times when there were shortages of natural vegetation in the surrounding areas. This led to trials and errors regarding the management and value of straws and other residues as well as removing forage from the nearby grasslands. Most forage was still collected by the grazing animal, on the commons, with fences used largely to keep livestock out of the planted fields. Eventually, mechanization began to be used for harvest and handling, storage and feeding systems were developed, and the livestock were fenced in rather than out. The need for stored forage and other feed sources increased.

FORAGES AND GRAZINGLANDS BEFORE CSSA

The CSSA was founded in 1955 as an offshoot of the American Society of Agronomy (ASA), nearly 20 yr later than the founding of the Soil Science Society of America (SSSA) that spun off from ASA in 1936. The emergence of SSSA was natural following the dust bowl and economic depression, placing emphasis on conservation of natural resources and a shift to use of chemical fertilizers and improved tillage practices for crop production. Further, soil science was emerging as an independent discipline as new concepts in basic soil chemistry, soil physics, and soil genesis were developing rapidly in Eurasia and North America. These findings and their applications, communicated through a series of International Soil Science Congresses, had effectively connected the world scientists.

The concept of Grassland Congresses began in 1920 when several scientists from northern and central Europe met to share information in an area of similar climates. It was expanded to a full International Congress in 1928. After a lull due to World War II, the Congresses resumed, with three held in North America; the sixth in Pennsylvania in 1952, the 14th in Kentucky in 1981, and the 18th in Manitoba/Saskatchewan in 1997. Goals have been to link researchers around the world to meet and share information on breeding and management of forages and grasslands. A series of International Rangeland Congresses, beginning in 1978 in Colorado, have focused on raising visibility of the value of rangeland with specific emphasis on social and biological values of rangeland ecosystems. Both Congresses meet about every 4 yr. Of significance, the International Grassland Congress and the International Rangeland Congress will meet jointly for the first time in 2007 in China. The common basic principles and research goals concerning

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Abbreviations: ASA, American Society of Agronomy; CSSA, Crop Science Society of America; NIRS, near infrared reflectance spectroscopy; NRI, National Research Initiative; PVP, Plant Variety Protection; SSSA, Soil Science Society of America.

forage and grazinglands management in more arid and more humid areas are being recognized.

Overall, as grassland scientists approached the midpoint of the 20th century, there was general recognition that basic aspects of forage and grassland science were less developed than comparable areas for annual crops. It was not until later that the basic principles of genetics, breeding methodologies, plant physiology, plant anatomy and morphology, and underlying principles of plant adaptation could be developed and applied to forage and grazingland species. In contrast with annual crops which receive more management attention by producers and are grown in the most desirable window of the annual climate, forages and grasslands are usually perennials and need to both survive and be productive under the prevailing year-round climate. This greatly increased the need for forage and grassland scientists to focus research on adaptation to climatic, biotic, and abiotic stresses associated with persistence, and the clear need for agronomic performance, forage nutritive value, and high quality as expressed by animal performance.

Recognition of the national importance of grass, in the broad sense, and the paucity of a compendium of information, led to the publishing of the first Yearbook of Agriculture that appeared in monograph format. It was simply titled "Grass" (USDA, 1948). The yearbook provided a detailed analysis of the situation and potential for grasslands and forages, including rangeland species and conditions. In the introductory chapter, Cardon (1948) noted that grassland management is complex and requires a high level of managerial ability to decide what grass to use in the cropping system and how it should be managed to optimize its multiple agronomic roles and the needs of livestock. He concluded there is much information drawn from experiences and a need for more information based on experimentation. Further, much more information is needed on the myriad of species used as forages, especially for basic understanding of the problems, their solutions, and how they can be incorporated into practice.

FORAGES, GRASSLANDS, AND GRAZINGLANDS IN CSSA

The time when CSSA was formed (1955) is significant for forages and grasslands as the world was emerging from World War II and the Cold War was beginning. Western Europe was leading in research on grassland management and new concepts in grazing management, and new grazing methods and systems were being used in New Zealand and Australia. Most developing countries were experiencing increased demand for ruminant products and international communication among scientists was easier. The economic and environmental roles of grasses and legumes in soil management and crop rotations were realized, and there was strong interest in supporting basic sciences to understand the specifics. Rapid advances were being made in animal nutrition, animal health, and reproductive biology. Similar advancements were being made in agricultural engineering that affected harvest, packaging, and storage of forages.

Forage and Grazinglands Education

To advance the science, there needed to be active programs in teaching new technologies and curricula that were science based. The first edition of the popular Forages textbook (Hughes et al., 1951) appeared just before formation of CSSA and utilized multiple authors to cover topics in more depth. Reflecting the rapid increase in discovery and application of science, the preface of the second edition (Hughes et al., 1962) noted the new emphasis was on the *why* rather than the *how* relative to management strategies. Innovative educators were reconstructing undergraduate courses covering forage crops and pasture management. There had been many new technologies developed during the previous two decades such as improved breeding methods, use of statistics, discovery of DNA, application of radioisotopes, developments of agricultural pesticides, rapid expansion in mechanization, and the movement toward specialization in livestock industries. In addition, increased interest of private industry, mainly associated with seed, fertilizer, and pesticides, was gradually assuming leadership in development of many technologies and informing producers about their use.

It was already apparent that forages were an important part of crop rotations as they conserved soil and added N to the ecosystem or rotation. In addition, there were growing interests in human nutrition and the role of animal products for health and quality of life. Cropping systems were rapidly changing in the Midwest and South as soybean [*Glycine max* (L.) Merr.] emerged as a major cash crop. The South had a decline in cotton (*Gossypium hirsutum* L.) production, and the use of horses and mules throughout the USA and Canada had decreased considerably. This allowed a rapid shift in area and types of livestock production systems, but these would require better and science-based strategies to manage the land resources in an economic and sustainable way. It was clear that improving plants and their management would require interdisciplinary efforts. Research must integrate plants, soils, animals, engineering, economics, and social values. Holistic thinking was needed when CSSA was formed.

Finding an Appropriate Division

Interestingly, when CSSA was formed the forage research community remained dispersed throughout the six original divisions (Table 1). Forage and grassland researchers interested in breeding and genetics were involved with Division C-1, those in physiology and ecology were in C-2, those in crop production and management were in C-3, those in seed production were in C-4, and those interested in crop quality were in Division C-6. This early arrangement for forage and grazinglands differed from that of Division C-5, Turf Management, which was already a separate division in ASA before formation of CSSA. Their arrangement allowed researchers and educators in the turf community to meet together, whereas forage and grassland researchers attended division activities according to their type of science. Joint sessions and symposia were used

Table 1. Crop Science divisions within the ASA before and after the CSSA was formed in 1963. Divisions 1 to 6 continued as ASA divisions after 1955.

Before 1963	After 1963
Div. 7. Crop Breeding, Genetics & Cytology	C-1 (1963 on)
Spun off Cell Biology & Molecular Genetics	C-7 (1985–2002)
Renamed Genomics, Molecular Genetics & Biotechnology	C-7 (2003 on)
Spun off Plant Genetic Resources	C-8 (1991 on)
Div. 8. Crop Physiology & Ecology	C-2 (1963–1964)
Renamed Crop Physiology & Metabolism	C-2 (1965 on)
Div. 9. Crop Production & Management	C-3 (1955–1964)
Renamed Crop Ecology, Production & Management	C-3 (1965–1999)
Renamed Crop Ecology, Management & Quality	C-3 (2000 on)
Div. 10. Seed Production & Technology	C-4 (1963–1985)
Renamed Seed Physiology, Production & Technology	C-4 (1986 on)
Div. 11. Turfgrass Management	C-5 (1963–1972)
Renamed Turfgrass	C-5 (1973–1987)
Renamed Turfgrass Science	C-5 (1988 on)
Div. 12. Weeds and Weed Control	C-6 (1963–1964)
Withdrew to form a new society	
Initiated Crop Quality & Utilization	C-7 (1965–1966)
Renumbered Crop Quality & Utilization	C-6 (1967–1999)
Renamed Forage & Grazing Lands	C-6 (2000 on)

during the annual meetings to integrate the components. This changed in 2000 when the Forage and Grazing Lands division (C-6) was formed to integrate all the forage and grassland researchers into one division.

But the route for formation of Division C-6 was circuitous. With rapid changes in physiology and biochemistry, mainly associated with photosynthesis and N_2–fixation, Division C-2 had a name change in 1965 with ecology moving to Division C-3, both being predominated by scientists interested in annual crops (Table 1). In addition, Division C-7 was formed in 1965 to focus on issues associated with crop quality and utilization, serving as a natural home for many forage and grassland scientists. They had some common interests in quality of annual crops, but the synergy was not great. In 1964, the weed scientists left ASA and CSSA to form their own Society, leaving the designation C-6 unused. Not being content with a missing division, Division C-7 was changed to Division C-6. Gradually, the forage and grazinglands scientists became the dominant group in Division C-6 with many others still being dispersed in other divisions. As conditions continued to change, especially in the 1990s, forage researchers began to identify with ecology (Division C-3) to a greater degree than with physiology (Division C-2), and the number of forage breeders and geneticists (Division C-1) was greatly diminished.

In 2000, considering the wishes of the research community and advantages of having a division focused on all aspects of forage and grazinglands, members of Division C-6 proposed renaming it Forage and Grazing Lands. The split wording of grazinglands, although not the common spelling, was presented by the division and approved by the CSSA Board of Directors in 2000. The same name was repeated in the revised CSSA bylaws that were approved by the CSSA members in 2005. Crop quality was added to Division C-3 in 2000. The new Division C-6 has prospered and is now more dynamic in the Society, as it incorporates most of the forage and grassland topics of interest. The Robert F Barnes Award, established by Division C-6 in 2004, recognizes outstanding graduate student presentations.

Today, Division C-6 is strong, and serves as a comfortable venue for scientists who have a common interest in forages and grazinglands, but contribute different levels of science and different perspectives. The synergism among diverse interests is apparent and the programs are more inclusive. Yet, associations with other divisions are still emphasized and many joint sessions are held at the annual meetings.

Eight of the 30 agronomists elected ASA Fellow in 1955 had earned the honor by working on forages and grasslands. They included Kling I. Anderson (KS), David F. Beard (USDA), Atlee L. Hafenrichter (USDA), Wesley Keller (USDA), Herbert H. Kramer (IN), Gerald O. Mott (IN), Royse Murphy (NY), and Robert R. Robinson (USDA). Despite the transitions in identity within the Society, members of Division C-6 have had, and continue to play, critical roles in the leadership of CSSA and in providing meaningful outputs. Gerald Mott, a renowned pasture agronomist, was elected in 1955 as the first President of CSSA. Including Mott, 21 of the 50 presidents of CSSA have been oriented toward forages and grazinglands in their research activity. These data attest to the levels of science and professional leadership that have arisen from within the discipline.

Need for a Journal Home

Despite the new society and the initiation of publishing *Crop Science* in 1961, some forage and grassland scientists still published their work in *Agronomy Journal*, especially if it related to soil–plant relations or was more applied, and in the Journal of Animal Science when oriented toward forage quality. *Crop Science* was chosen as the outlet for more basic studies in forage genetics and breeding and in physiology and nutritive value. There was general concern about the editorial and review policies regarding publishing grazing studies, site-specific applied studies, and systems studies on forages and pastures that were less amenable to the expected statistical procedures. These issues were at least partially responsible for the decision of ASA, CSSA, and SSSA to initiate the applied *Journal of Production Agriculture* in 1988. Research reports on forages and grazinglands were very prominent in that journal which, for a range of reasons, was discontinued in 1999.

The loss of the *Journal of Production Agriculture* led several North American forage and grazinglands specialists to again publish their applied and grazing research in *Grass and Forage Science*, a journal of the British Grassland Society, the *Journal of Range Management*, published by the Society for Range Management based in Denver, CO, and the *Journal of Animal Science*, published by the American Society of Animal Science, based in Savoy, IL. In 1992, The American Forage and Grassland Council, based in Georgetown, TX, responded to the need to publish research by changing the name of its annual publication to *Proceedings*, began assigning Volume and ISSN numbers to each, and edited all the papers submitted for publication. This increased the scientific quality of the publication, provided a more useful outlet for applied research and was made easier to reference.

With the rapid increase in electronic media and the continued need for an outlet for publishing applied or site-specific research data in refereed scientific papers in the area, CSSA cooperated with the plant management network in 2004 to initiate the electronic journal entitled *Forage and Grazinglands* to publish peer-reviewed papers and other materials in an easily accessible format for peers and practitioners. The journal is multidisciplinary, science-based and fully citable. The editorial board is heavily represented by CSSA members and the journal is contributing to needs of the division.

ACADEMIC CONTRIBUTIONS

Textbooks and Student Resources

The concept of grassland agriculture emerged to emphasize the multifunctional roles of soil conservation, livestock feed, livestock health, soil improvement for other crops, crop rotations, and other intrinsic values including aesthetics. The idea was proposed early (Cardon, 1931), but was not really emphasized until later (Cardon, 1952). This was exemplified by Heath in the first edition of Forages (Heath, 1951) when he asked the question "What is grassland farming?" and later in the second edition (Heath, 1962) when he rewrote the chapter more affirmatively as "Grassland agriculture." In both, he emphasized that quality forages are the hub of a sustainable agriculture. Many other agronomists throughout the USA endorsed the concept. Subsequent editions of Forages (Barnes et al., 2003), the leading textbook in the area, continue to focus on basic aspects and the holistic approach to grassland agriculture.

Other undergraduate books of a more regional coverage also contributed to the integration and advancement of knowledge. For example, Walton (1983) focused on basic science aspects of forage and grassland management with some emphasis on the western provinces of Canada. Miller (1984) authored a textbook based on his undergraduate course at Illinois. Ball et al. (1991) authored a user-friendly applied textbook, now in its third edition, on managing forages adapted to the South, and Horrocks and Vallentine (1999) authored an undergraduate textbook that emphasized forage production in high-yielding environments, usually irrigated, with major application to the intermountain west. These textbooks have been augmented by scores of research reviews and symposium proceedings on specific topics that have been used in graduate education.

Need for Basic Research

About the same time as CSSA was founded, Harlan (1956) wrote a treatise on grassland agriculture and broadened the focus to include extensively managed areas of natural grasslands and desert shrubs. Emphasized was the intrinsic linkage of the animal, plant, and soil, with focus on the basic theory and science of plant physiology, ecology, forage nutritive value, soil science, and animal science. The goal was to allow transfer of principles for the development of local practices. He also emphasized the interconnections that would require better understanding of the overall system and solutions to animal and plant management. Even Phillips Petroleum Company was interested, emphasizing that "grass is indeed our basic heritage," and "of all the things that live and grow on this earth, grass is the most important." They emphasized that range resources are renewable only if well managed. To that end, they published a series of well-illustrated booklets (e.g., Phillips Petroleum Company, 1955) that covered native grasses, legumes, and other forbs, undesirable grasses and forbs, and poisonous grassland plants. Information on adaptation areas, quality, and management was included.

A short time later, Dale Smith (1962a) authored a book for advanced undergraduate and graduate students that emphasized physiological characteristics and principles to serve as a basis for managing forage grasses and legumes. His recognition of the need to apply basic sciences was instrumental in linking even more biochemistry, biophysics, and meteorology into the decision-making process. Following on that effort, an ASA Special Publication on Forage Plant Physiology and Soil-Range Relationships emanated from a symposium at the 1963 ASA/CSSA meetings (Keller et al., 1964). In the preface, H.B. Sprague, President of ASA, wrote "This volume brings into one place certain salient features of our knowledge on forage plant physiology and soil–plant relationships." More detailed descriptions and applications of physiology of range plants were published by the Society of Range Management (Sosebee, 1977).

Research Workshops and Reviews

Recognizing the need for consolidating new findings associated with forage nutritive value and quality, ASA, the American Dairy Science Association, the American Society of Animal Production (presently the American Society of Animal Science), and the American Society of Range Management formed a committee to publish an advanced interdisciplinary book on research techniques associated largely with forage nutritive value (ASA, 1962). Later, Butler and Bailey (1973), with several authors from CSSA, published the three-volume series on chemistry and biochemistry of herbage, a detailed compendium of the nature of forage plants, and implications for forage nutritive value and management. These books integrated research of the various disciplines and were often used in graduate classes in plant and animal sciences.

Often in cooperation with ASA, CSSA has published numerous monographs, symposium proceedings, and special publications focused on forages and grazinglands. Societal monographs have been written on alfalfa (Hanson, 1972; Hanson et al., 1988), tall fescue (Buckner and Bush, 1979), clovers (*Trifolium* spp., Taylor, 1985), cool-season grasses (Moser et al., 1996), silages (Buxton et al., 2003), near-infrared spectroscopy (Roberts et al., 2004b), and warm-season (C_4) grasses (Moser et al., 2004). In addition, special publications include ones on antiquality components (Matches, 1973), grazing research methods (Marten, 1989), contributions from breeding (Sleper et al., 1989), postharvest preservation (Moore and Peterson, 1995), molecular technologies for breeding (Brummer et al., 1998), birdsfoot trefoil (Beuselinck, 1999), and native warm-season grasses (Moore and Anderson, 2000). Others involving C-6 members include those on agroforestry (Garrett et al., 2000), management of agroecosystems (Rickerl and Francis, 2004), and dryland agriculture (Rao and Ryan, 2004). Books of note emanating from symposia and conferences include those on legume persistence (Marten et al., 1989), cell wall structure (Jung et al., 1993), forage quality (Fahey et al., 1994), and pasture and forage crop pathology (Chakraborty, 1996). Collectively, these form a timeline of comprehensive coverage of research findings and interpretations on relevant topics.

Trends and Highlights in Production

Because *Crop Science*, the official journal of CSSA, was not published until 1961, Volume 47 of *Agronomy Journal*, issued in 1955, was used as a state of the art publication concerning the sciences of forages and grazinglands at the time CSSA was formed. Several papers were published on forages that were arbitrarily subdivided into subject and species (Table 2). The numbers do not add because in some cases more than one factor or species was studied. Most of the breeding papers dealt with disease resistance, stand longevity or production, whereas the other papers covered a range of production issues and quality factors. There was little emphasis on environmental issues. The distribution of species is somewhat similar to today except for the very noticeable lack of papers on tall fescue, mainly because its value was not yet broadly realized. The desire to find or develop a reliable legume was prominent.

A listing of subjects and species topics for 2005 to compare with the data in Table 2 is not feasible. Research publications today on forage and grazinglands occur in a wide range of resources including several international journals (see above). Science is much more international than it was only 50 yr ago, communication is nearly instantaneous, and political, geographic, and language boundaries for science are much less restrictive. Even cooperative research transcends distances, and the basic principles of plant growth and utility are easily transferred and applied. Conversely, research findings from the private sector continue to be proprietary, a significant professional price that is paid for the great products they provide.

Somewhat ironic, the first paper in Volume 47 of *Agronomy Journal* (1955) was on grasslands and authored by D.R. Dodd, a retired professor of Agronomy at the Ohio State University (Dodd, 1955). His assessment followed an extended visit to Europe where he observed European forage technology was ahead of the USA and Canada. Areas of interest were land use and conservation, needs for new cultivars and plant diversity, the roles of nondomesticated animals on grasslands, the need for rest periods, the value of alfalfa, and the new potentials for stored feeding (Table 3). Also, he emphasized fertilizing pastures for production and weed control. He encouraged research on these areas, a role the newly formed CSSA could facilitate. Not surprisingly, many were pursued and later published. Note that Dodd concluded the rewards to farmers are more than economic!

Mixtures, Pure Stands, and Mixtures

Of note was the gradual shift from almost exclusive use of mixtures of several species in cultivated pastures and hay fields in the early 1950s. These broad-based mixtures, including several legumes and grasses, were favored as the combination of species buffered changes in production and nutritive value across a range of soil sites, reduced disease and insect challenges, and improved the seasonality of production. Then, prices of fertilizer N gradually decreased during the 1960s so yields of grasses could be increased, and the new alfalfa cultivars were more stress tolerant, allowing less risk of winter injury in pure stands. Additional basic information gave insight on how to manage each grass and legume based on its distinct physiology and morphology, such that each monoculture could be managed to realize its potential, especially when the forage was harvested for hay.

Table 2. Number of manuscripts in Volume 47 (1955) of *Agronomy Journal* based on subjective classification into various forage subject areas and forage species.

Subject area	No.	Forage species	No.
Genetics/breeding	15	alfalfa	10
Establishment	5	ladino clover	5
Forage yield	5	red clover	2
Seed yield	6	white clover	1
Plant nutrition/nutrients	4	crimson clover	1
Forage quality (protein)	1	smooth bromegrass	4
Forage quality (other)	4	orchardgrass	4
Persistence		bahiagrass	1
Stand longevity	3	bermudagrass	1
Cold tolerance	4	dallisgrass	1
Drought tolerance	1	corn silage	2

Table 3. Abridged assessments of Dodd (1955) following an extended tour to observe grassland practices and research in Europe.

Land use and soil conservation need new and better grasses and legumes
Do our livestock need more variety of species in our pastures?
What are roles of rodents, insects, ants, earthworms, etc. on grasslands?
Stored feeding gives highest production of animal products per acre
Silage is important; trench silos are economic for grass silage
There is value and need for research on alfalfa
Grasses cut every 4–5 wk have very high protein content
Rotational grazing with energy supplementation for dairy cows is very economic
Fertilization is the easiest way to control weeds and brush
Nitrogen is used liberally on the most productive farms
Surface applied lime and fertilizer are effective on pastures and hayfields
Production of permanent pastures can be increased by P and grazing control
Liquid manure can be effectively applied on pastures
We need more soil and plant testing of forages
The pleasures of farming are not all in the income

Alfalfa is still usually grown in monoculture to gain the advantage of its nutrient value, but as energy costs increased and N became more expensive, there was a renewed emphasis on use of legumes in mixture with grasses for pastures and hay fields. Nitrogen fixation was only part of the reason for using more legumes, however, as better analysis techniques clearly showed the superior quality of the mixture and seasonal productivity was more consistent (Burns and Standeart, 1985). This again raised the interest in clovers, birdsfoot trefoil (*Lotus corniculatus* L.), and annual lespedeza [*Kummerowia striata* (Maxim.) Makino] for cool-season pastures, and caused renewed interest in legumes adapted to the South.

Two significant changes further enhanced interest in grass–legume mixtures. One was the rapid increase in grazing management technologies and the shift to intensively managed pastures. Reducing harvesting costs, while maintaining high nutrient value, was the goal. The other was the shift to an ecology-based management system. In this case, the multifunctionality of forages and grasslands was being recognized and deemed valuable as a management objective. New emphases were placed on the role in nutrient cycling, soil erosion abatement, habitat and food sources for wildlife, and even the aesthetic values of hay fields, meadows, and pastures. This is consistent with desires of the public and new policies on manure and nutrient management (Cherr et al., 2006). This trend has also caused forage and grassland scientists to develop and use new tools and methods to understand the biological and environmental roles of species diversity. Today, the roles of each species in the broad mixture are being assessed from ecological and animal production perspectives.

ADVANCEMENTS IN SPECIES

Following up on Dodd's (1955) assessment, there have been major advances in most forage species in the USA and Canada, but we chose to highlight three. These are the rapid development of alfalfa as a forage crop with high nutritive value for dairy cattle, the emergence of tall fescue as the major species in the transition zone, and the dramatic improvements in bermudagrass as the perennial forage for the South. Each had unique challenges to overcome and researchers were required to use innovative ways to accomplish them.

There were also advancements in other forage species that, on the national basis, were of a lesser scale economically, but regionally had major impacts. Of particular note is the reintroduction of ladino clover (*Trifolium repens* L.) in the humid Eastern USA. Starting in 1937 North Carolina scientists found that ladino clover excelled if fertilizer (P, K, and lime) applied to common white clover was doubled. Ladino clover production increased in North Carolina from nil in 1944 to >122 000 ha by 1949 and >405 000 ha by 1952. This phenomenon was also occurring in adjoining states and today ladino clover remains the major pasture legume in the humid East.

Such impacts were also noted for use of ryegrasses (*Lolium* spp.) as winter crops in bermudagrass systems in the South, the subsequent improved disease and stress tolerance in white clover, and the recognition of the pasture value of birdsfoot trefoil (*Lotus corniculatus* L.). In connection with the need for environmental preservation and a move toward natural ecosystems, the native grasses, particularly the native warm-season grasses, have received considerably more emphasis. Where adapted, they have potentials for sequencing of pastures by using warm-season species during the warmer parts of the growing season, while cool-season species are rested.

Alfalfa Was Privatized

Alfalfa was well-known as an excellent hay crop for dairy production, but winter hardiness tended to be a major problem. In a landmark paper, Smith (1955) showed significant differences among seedlots of alfalfa cultivars that originated from different states. Advancing generations of seed increase in southern latitudes gave taller plants in Wisconsin and more winter injury. This led to many other basic studies and finally the development of seed production standards that both preserved the genetic purity of new cultivars and encouraged the western seed industry. Further, considerable research on physiology, morphology, and nutritive value of alfalfa gave a good scientific base for important characters and showed the way for industry to become involved.

Adoption of the Plant Variety Protection (PVP) Act in 1970 and strengthening of intellectual property protection opened the doors for private research and breeding programs on alfalfa and the eventual takeover of nearly all the plant breeding and seed industry in North America (Barnes et al., 1988). Most seed is now produced in Western states where management is specialized and yields are much higher than in the Midwest. Today a wide range of alfalfa cultivars is available from the private sector with resistance to multiple diseases (Lamb et al., 2006), several insects (Ranger and Hower, 2001), grazing tolerance (Smith et al., 2000), and adaptation to specific climatic regions.

Similar to alfalfa, seed of most cool-season grasses and many other legumes is produced in the Pacific Northwest, where the climate is ideal and the seed yields are much higher than in the Midwest. Even though the same PVP legislation offers protection, in only a few cases has private industry maintained interest in breeding programs for these species. Major challenges are the longer rotations of grasses so less seed is needed and the problem of minimal enforcement to deter brown bagging of protected cultivars. Forage grasses produce abundantly in spring, encouraging producers to harvest seed for added income even if the cultivar is protected. Legumes other than alfalfa are often used in mixtures where genetic differences among cultivars are masked such that common seed is a low-cost competitor. The lack of active involvement of the private sector in the breeding of grasses and other legumes has probably been a disadvantage to producers who could benefit from new technologies.

In 1975 an international conference, sponsored by the National Science Foundation, USDA, and others, was held to determine basic research needs of plant agriculture (Brown et al., 1975). The focus of the conference was on the fundamental biological processes that control productivity of economically important food crops, but many principles could be applied to forage grasses and legumes. This conference unified the basic science community and solidified the need for basic research that subsequently led to the USDA-National Research Initiative (NRI) program.

The NRI program greatly increased the rate of progress in understanding basic and applied aspects of photosynthesis, respiration, nitrate metabolism, N_2 fixation, and stress resistance of plants used as forages and in grazinglands. Particularly, in alfalfa, great strides were made in understanding genetic and environmental regulation of photosynthesis (Heichel et al., 1988) and N_2 fixation (Vance et al., 1988). More recent advances were made in understanding roles of vegetative storage proteins in regrowth and winter survival (Volenec et al., 1996), mechanisms of crown development (Nelson et al., 2001), and the importance of yield components (Volenec and Nelson, 1995). In addition, there were advances in understanding grazing tolerance (Brummer and Bouton, 1992) and autotoxicity (Chon et al., 2006). As the NRI programs expanded, parallel improvements were being made in disease resistance, glandular hairs were shown to be effective for resistance to potato leafhopper (*Empoasca fabae* Harris) (Ranger and Hower, 2001), and many alternative uses were researched for this high-yield and high-protein crop.

In spite of the vast array of basic research, there has been minimal if any genetic increase in forage yield of alfalfa (Brummer, 1999; Volenec et al., 2002; Lamb et al., 2006), unless environmental conditions lead to stand loss of older cultivars that lack multiple disease resistance. The reason for the yield limitation is not known, but Hill et al. (1988) suggested it could be due to partitioning of assimilates and the need to balance production and survival. Most breeders have emphasized multiple disease resistance which has also contributed to improved nutritive value by maintaining a higher proportion of leaves. There is some evidence that plant density of more recently released cultivars is higher and they may have better persistence, especially in environments where disease pressure is high (Lamb et al., 2006).

Not surprisingly, the situation is similar for most cool-season grasses and other legumes. For example, Casler et al. (2000) found that yield of smooth bromegrass (*Bromus inermis* Leyss.) did not increase among cultivars released between 1942 and 1995, but there were small improvements in resistance to brown leafspot [caused by *Pyrenophora bromi* (Died) Drechs.] and in forage nutritive value. They attributed the minimal response to the complex polyploid nature of the species, breeding emphasis on traits other than yield, the limited involvement from the private sector, and the low number of public breeding programs. Several researchers have pointed out the negative effects of leaf disease lesions on forage nutritive value (Mainer and Leath, 1978). In these cases, even though yield is similar, cultivars with improved disease resistance may lead to better plant persistence and higher animal output. In contrast, using recurrent restricted phenotypic selection, yield of bahiagrass (*Paspalum notatum* Flugge) was increased by >40% (Burton, 1982).

The future of alfalfa is bright as *M. truncatula*, a close relative of cultivated alfalfa, has been selected as the model species for legume biotechnology. The vast amount of basic research on this species should allow progress on several nutritive value and value-added traits for alfalfa (Samac and Temple, 2004). Genetic resistance to more pathogens and insects, improved tolerance to compacted soils and animal grazing, and tolerance to potato leafhopper is already being marketed. Roundup-Ready (Monsanto Chemical Co., St. Louis, MO) alfalfa is now available and potentials for developing bloat avoidance are encouraging. New thrusts in improving plant persistence and nutritive value of stems may also benefit from breeding and biotechnology.

Tall Fescue in the Transition Zone

There was no reference to tall fescue in the 1955 volume of *Agronomy Journal*, but the species was already gaining recognition in Kentucky and some adjoining states in the transition zone. Its characteristics of being robust, adapted to a wide range of soil types, competitive with weeds, highly tolerant to grazing, responsiveness to N, and good nutritive value are coupled with good drought tolerance and exceptional fall growth that extends the grazing season well into the winter (Buckner et al., 1979b). Despite its reputation of low animal performance, its agronomic features were superior to timothy (*Phleum pratense* L.), orchardgrass (*Dactylis glomerata* L.), and Kentucky bluegrass (*Poa pratensis* L.), especially when grazed during the warm months of midsummer. Consequentially, it was popular for beef cow–calf producers throughout the transition zone. Further, it produced abundant seed in the transition area to give an additional income source. Missouri and Kentucky continue to be leading states in production of seed.

Seed of 'Kentucky 31', a naturalized ecotype from Kentucky, and 'Alta', an improved cultivar from Oregon, was available in the mid 1940s and the species value was becoming realized, but with caveats about palatability and daily animal performance (Hanson, 1979). Area planted to the species expanded rapidly as it was promoted for forage, pasture, and soil conservation. Demand for seed increased dramatically, from about 14 million kg annually in the USA in the mid 1950s to nearly 57 million kg annually 20 yr later (Buckner et al., 1979a). Most stands in existence today were planted to those cultivars, many as long as 40 or 50 yr ago, giving some perspective to the vast area planted to this species. Coupled with its widespread use for roadsides and lawns, it has been argued that tall fescue has saved more soil in the transition zone in the last 50 yr than all the government programs combined! It also revolutionized the livestock industry as the transition zone became specialized in beef cow–calf operations.

The strong interest in improving cultivars and management of tall fescue, especially for nutritive value, led to a rapid expansion of both applied and basic research. From its humble beginnings some 50 yr ago, the amount of research on tall fescue grew rapidly to the point that the knowledge base was nearing that of perennial ryegrass (*Lolium perenne* L.). Basic research on adaptation, photosynthesis, morphological development, water relations, and mineral nutrition formed the basis for management decisions (Buckner and Bush, 1979; Nelson and Moser, 1994; Nelson, 1996). Few insect or disease problems were apparent. There was growing interest in grazing methods and pasture systems to use this popular species more effectively.

But the management challenges of producing forage with a very acceptable nutritive value, but suppressed animal performance as exhibited in the animal syndromes of fescue foot, fat necrosis, and poor performance during summer kept nagging producers. Three major approaches were used to offset and eventually solve the problems. All involved a number of scientists in several disciplines. Early it was recognized that high rates of N aggravated the syndromes, but reasons were unknown. Researchers at Kentucky reported experimental results showing that incorporating modest levels of legumes improved the nutritive value of the mixture and partially alleviated the severity of the adverse syndromes.

Other scientists contributed to learning practices for renovation with legumes. Studies of shade tolerance effects and seedling vigor (Gist and Mott, 1958) pointed to the potential of red clover (*Trifolium pratense* L.). Many studies were conducted on tillage, grazing, herbicides, growth regulators, and other methods to weaken the competitive tall fescue sod (Taylor et al., 1979). Reliable methods were worked out, but challenges of keeping the legume in the stand were still there. Tall fescue was competitive and had to be managed to favor the legumes.

Breeding efforts to improve nutritive value with some success were focused on laboratory digestion methods (Bughrara et al., 1991) and use of intergeneric crosses with ryegrass to breed for leaf characters (Buckner et al., 1979b). A critical contribution by Charles Bacon, a plant pathologist, and his colleagues opened the door for exploiting the potential of tall fescue when they discovered the presence of an endophytic fungus that was not associated with nutritive value, but with poor animal performance (Bacon et al., 1977). Some tall fescue breeders purged their breeding materials of the endophyte, but the resulting plants had poorer stress tolerance and vigor. The symbiotic action of the plant and endophyte produces alkaloids that improve agronomic performance, but are negatively associated with animal production (Bush et al., 1993). So, new techniques were used to introduce novel endophytes into tall fescue that improve adaptation to plant stress but do not reduce animal performance. They are currently being evaluated.

The area planted to tall fescue has stabilized somewhat in the USA. New cultivars with novel endophytes that alleviate summer syndrome are available for new and replacement plantings. In addition, it is now known that several other grasses have endophytes of various degrees of biological significance. Zhang et al. (2006), as part of a larger review, presented an excellent section on the potentials of exploiting the endophyte relationship in tall fescue and other grasses. Transformation techniques are known for tall fescue and recent advances in genomics and biotechnology offer a great potential for continued genetic improvement (Wang et al., 2001).

Bermudagrass Covers the South

Bermudagrass received a mixed reaction when first introduced to the South, as it had weed-like characters, but as the area planted to cotton decreased, it became the species of choice for pastures. It reproduces vegetatively by stolons and rhizomes, making it ideal for soil conservation and, once improved, the genetic makeup is fixed. It also forms hybrids. Glenn Burton, a long-term USDA plant breeder at Tifton, GA, and member of CSSA, cannot be separated from the agronomic development, breeding, and rise to prominence of bermudagrass. His substantial contributions to improving bermudagrass and agriculture in the South have been recognized with membership in the National Academy of Sciences.

'Coastal', a hybrid, was released in 1943 (Burton, 1954) and proved to be more winter hardy, more disease resistant, higher in forage yield, and provided better animal performance than common bermudagrass. It was also taller and was useful for hay production. Burton's subsequent cultivars, including hybrids such as 'Coastcross-1' (Burton, 1972), continued to increase yield and several also had even greater nutritive value. Consistent with expectations, the small genetic increases in nutritive value gave large increases in annual weight gains of grazing cattle. The South had a species that was adapted, high yielding, and had adequate nutritive value. It was also superior in soil conservation.

With good cultivars available, the agronomic characters could be exploited. Bermudagrass was adapted to a range of soil types, was very responsive to N, competed with weeds, and yet was compatible with legumes such as clovers that could extend the grazing season. Alternatively, cool-season grasses can be interseeded into bermudagrass in the fall to give additional winter and early spring production. Bermudagrass does well with high grazing pressure, which helps maintain young leaf tissue in the canopy to improve nutritive value. On a national scale, bermudagrass has had a dramatic effect on the livestock industry and abatement of soil degradation in the South.

ASSESSING NUTRITIVE VALUE

Reports of nutritive value estimates of forages, such as crude protein and fiber fractions, as opposed to quality estimates (predicated on animal daily responses which are not addressed here), were limited in the formal agronomic literature in 1955 when CSSA was founded. Nutritive value measurements were reported in only three articles in Volume 47 of *Agronomy Journal* and consisted of simply crude protein (Sullivan and Roulley, 1955; Willhite et al., 1955) or proximate analyses. Proximate analyses (following the Weende system proposed in the 1800s) consist of measures of crude protein, crude fiber, ether extract, nitrogen-free extract, and ash (Wakefield et al., 1955). The following year Sullivan et al. (1956) noted that crude fiber was inadequate as an estimate of carbohydrate availability and suggested the use of cellulose and lignin. Likewise, nutritive value was presented in two 1955 articles in the *Journal of Animal Science* and expressed as proximate analyses (Fontenot et al., 1955; Long et al., 1955). Three articles appeared in a similar form in 1956 (Erwin et al., 1956; Lloyd et al., 1956; Watkins and Kearns, 1956).

At the onset, *Crop Science* was the domain for plant-breeding contributions, with no estimates of nutritive value reported in Volume 1 (1961). The lack of nutritive value reports was also noted in the same year for the *Agronomy Journal* (Vol. 53, 1961), whereas in the 1961 *Journal of Animal Science* (Vol. 20) proximate analyses were presented in only two papers as estimates of nutritive value (Alexander et al., 1961; Kane et al., 1961). Lack of information in journals on the nutritive value of forages during this period is consistent with documentation that much of the early forage- and pasture-related research was reported in technical or general bulletins or research fliers (Burns, 2006).

In Volumes 2 and 3 of *Crop Science*, reports on aspects of nutritive value consisted of only water-soluble carbohydrate concentrations of grasses (Smith, 1962b) and crude protein status of forages (Craigmiles and Newton, 1962). From 1962 through 1966 (Vol. 2–6) forage palatability was assessed as a component of breeding programs (Buckner and Burrus, 1962; Craigmiles et al., 1964; Gangstad, 1964, 1966), but nutritive value was not reported.

In the early 1960s, however, the approach to nutritive value estimation changed, moving away from proximate analyses to other constituents (Cook et al., 1961). Predictive approaches were emerging using marker techniques (Lofgreen and Meyer, 1956), in sacco (nylon bag), and in vitro procedures (Donefer et al., 1960; Hart, 1967). In vitro procedures were reported before the 1960s (Quicke et al., 1959), but they were very limited in capacity and generally not a part of forage evaluation. But, as time progressed, the analytical techniques and their application increased rapidly, leading to positive changes in the basis for management decisions and the way new cultivars were developed.

Progress in attaining improved methodologies to properly fractionate plant tissue in a way meaningful to explain animal performance on a daily basis has been rather subtle. Generally, small contributions by different scientists, one building on the other, have led to positive results and have been summarized for the general forage and forage-animal areas (Reid, 1995). In this process a key contribution by any one individual is frequently masked or the individual's identity lost. In the past 50 yr, since formation of CSSA, we concluded there were four major achievements regarding nutritive value. Many valuable contributions that we did not reference occurred within each to facilitate advancement. Recent and excellent reviews are available that document those developments and are appropriately cited (Burns, 2006).

Strategic Partitioning of Forage Dry Matter

Proximate analyses was the major method for estimating nutritive value in the 1950s. The concept of dividing the forage dry matter into digestible and indigestible fractions (Van Soest, 1965), with the former consisting of a soluble and an insoluble, but partially available, portion, was a critical step in moving beyond proximate analyses (Van Soest, 1963a, 1963b, 1969). The soluble portion can be utilized by enzymes in the digestive tract, whereas the insoluble, partially available portion requires rumen microbial breakdown (Barnes, 1973). The fiber fractions that ultimately emerged as important were neutral detergent fiber, acid detergent fiber, and lignin (Van Soest and Robertson, 1980).

Innovation and progress has occurred regarding the nature of the cell wall polysaccharides (Moore and Hatfield, 1995) and the associated toxic plant secondary metabolites (Foley et al., 1999; Bush and Burton, 1995). Likewise, the indigestible moiety of the cell wall (i.e., lignin) and its influences (Allinson, 1969) was the subject of a comprehensive symposium on the forage cell wall structure and digestibility (Jung et al., 1993). Specific reference to this topic in the resulting proceedings include Himmelsbach (1993), Jung and Deetz (1993), Van Soest (1993), and Buxton and Casler (1993). The emergence of nutritive value constituents as an index of forage quality or as a predictor of forage quality has been reviewed in detail by J.E. Moore (1995).

Dry Matter Bioassays

Before forage nutritive value can have utility as an index of forage quality, it requires a link with animal daily response. This relationship was lacking during the 1950s and attributed by Reid and Klopfenstein (1983) to the complexity of the plant–animal interface and a shift away from pastures during that period. The integration, however, of plant dry matter and its soluble and nonsoluble portions and microbial breakdown (i.e., rate vs. extent of digestion; Fisher et al., 1989), was being addressed in the pre-1950s using limited in situ procedures (Lowery, 1969). This process involved the placement of nylon bags containing cellulosic material into the rumen and determining in sacco dry matter disappearance.

However, an in vitro measurement with similar crossover methodology, i.e., integration of the forage nutritive value and animal response with microbial consideration, was described by Tilley and Terry (1963). This bioassay consisted of a two-stage in vitro digestion procedure, and of significance, was scaled to be useful in evaluating large numbers of samples. The procedure was slightly modified in the USA and evaluated as a regional project (Richards, 1969) on forage utilization and evaluation. Its use, with some local modification, has become the method of choice to integrate the soluble and partially degradable portion of the plant dry matter (Barnes, 1969). Advancements in various fermentation methods have been described and compared by Barnes (1973), as has the comparison of in vitro fermentation as well as fungal enzyme methods to estimate forage digestibility (Marten and Barnes, 1980; Weiss, 1995).

Near Infrared Reflectance Spectroscopy

The application of Near Infrared Reflectance Spectroscopy (NIRS) to agricultural products was first reported by Ben-Gera and Norris (1968) in the late 1960s. This technology uses the electromagnetic spectrum, and consists of the electromagnetic radiation stretching from high-energy, short wavelengths of cosmic rays to long-wavelength radio waves. The history of NIRS development has been recently addressed by Shenk and Westerhaus (1995). A complete treatment from the understanding and use of NIRS through its application in analysis of food crops, processed foods, and nonfood products has been recently reviewed (Workman and Shenk, 2004). The application of NIRS to estimating nutritive value of forages has been addressed by Shenk and Westerhaus (1995) and most recently by Roberts et al. (2004a), with an overview of the potential direct prediction of in vivo digestion and dry matter intake (Coleman et al., 1999).

The significance of NIRS in forage evaluation resides mainly with the need for minimal sample preparation, the small amount of sample required, the short length of time (minutes) required to predict a large number of nutritive value estimates, and in vitro dry matter disappearance from the same scan, recovery of the unaltered sample when in limited supply, and its degree of accuracy and precision when properly calibrated. The benefit of directly predicting animal response via NIRS, after calibration has been completed, resides with magnitudes of cost reduction associated with small quantities of experimental forage compared with that required for large-animal intake (Burns et al., 1995) and digestion (Cochran and Galyean, 1995) studies, which are also both facility and labor intensive.

Understanding Antiquality Factors

The worth of high nutritive value of forage has been known for a long time, as evidenced by the development of improved management strategies and breeding emphasis on disease resistance. Adding legumes to grass pastures (Burns and Standeart, 1985) and improving management of grazing systems improves animal performance (Gerrish, 2004). Also, breeding efforts have demonstrated that small genetic increases in quality of bermudagrass and switchgrass (*Panicum virgatum* L.) have led to large increases in animal gain (Vogel and Sleper, 1994). Intake is usually considered to be more important as a quality component than digestibility, but is very hard to measure in numbers sufficient for breeding programs. Intake is highly correlated with digestibility, however, so selecting for digestibility alone should improve both.

Improving nutritive value can occur by increasing concentration of plant factors with high digestibility or reducing those factors that have low digestibility. Considerable information is becoming available from basic studies on cell wall composition and structure, yet the roles of secondary metabolites, often soluble, on nutritive value and quality, need more attention. Some of these may contribute to taste, aroma, or other deterrents to intake. They may also interfere with the health of the animal or reduce the rumen microbial activity. In addition, there are many plants that would be acceptable as forages if the physical factors such as thorns were reduced. With the maturing of biotechnology there may be even more opportunities for improvement of nutritive value and utilizing the multiplier-effects that improved nutritive value has on animal performance.

OTHER SIGNIFICANT ADVANCEMENTS

Mechanization of Hay Making

Since antiquity, making hay has been a labor-intensive practice and was not always timely. The mechanical hay baler that grew in popularity in the 1950s was helpful, but considerable labor was still required for putting hay into storage and then for subsequent feeding. The advent of the large round baler in the early 1970s has been revolutionary in the transition zone and the South, although it took considerable research on packaging, storage, and feeding to make it effective. The large bales could be moved to storage outside and later fed using mechanical power. At first, spoilage due to weathering was an issue, but soon technologies were developed to reduce storage losses. New technologies like vinyl bale wraps and tube silos offer new potentials for reducing spoilage during storage.

Grazing Methods and Systems

Since forage nutritive value and minimizing stored feed were important economically, the concept of grazing for as much of the year as possible was considered to be advantageous. Maintaining animals by grazing also distributed the manure and urine back onto the pasture. The emergence of solar-powered fencing technologies and improved watering systems were critical to make the more intensive systems feasible. Special short courses on grazing were offered for producers and technical specialists as popularity grew. Systems based on tall fescue and bermudagrass pastures (extended with legumes or cool-season grasses) were especially successful. Pasturing is also more consistent with public desires about animal welfare.

Establishment of Consistent Markets

Most forage crops have not been marketed effectively, as there is a lack of organized marketing systems and few were using measures of nutritive value as a value-added character. The adoption of NIRS technologies changed this as nutritive value could be measured quickly and at low cost. Soon hay markets were organized and pricing was more consistent with the expected animal performance. Now there are expanding international markets that require measures of nutritive value. In addition, large high-density bales facilitate long-distance transport to broaden market areas. Having access to forage of defined nutritive value has allowed specialization whereby contracts can be written between animal owners and distant forage producers.

Multifunctionality of Forage and Grazinglands

New uses of forages are being discovered on a regular basis. Uses of forages as a source of a natural protein, a pharmaceutical, or as food additive for sustained human health are now feasible and in some ways already in production. Many forage species such as switchgrass could be good sources of bioenergy and biological feedstocks for manufacturing needed products (Sanderson et al., 2004). New roles in carbon sequestration are being investigated. In many areas, grazinglands are used by the public on a fee basis for hunting, observing wildlife, or just communing with nature. The public values pastoral settings.

Potentials for Biotechnology

Significant advances through biotechnology have been made in many crops and some in forages, most notably glyphosate resistance in alfalfa. Even so, concern exists in the forage and grassland community, and especially the public, about using genetic engineering in forages that are directly consumed by meat- and milk-producing animals. Forages are considered unique and *natural* feed sources for ruminants, which differs from the general acceptance of the same animals consuming corn (*Zea mays* L.) or soybean that has been genetically engineered. It is unclear why these divergent opinions exist or how rapidly they will change.

Despite the concern, research on biotechnology of forages continues as it holds a great deal of potential as reviewed by Wang and Ge (2006). The authors recognize, just like the early advocates of grassland agriculture, that forage grasses are critical to sustainable agriculture and contribute greatly to the world economy. They highlighted several areas where application of molecular biology techniques could help breeders make progress.

THE NEXT FIFTY YEARS

Major advances have been made in forage research during the past 50 yr. A number of the most significant have occurred in the latter half and are attributed, in part, to the previously generated knowledge base. Most of the past progress in all areas of forage and grazinglands research has resulted from appropriated funding delivered through the land grant system, that is, State Agricultural Experiment Stations, and the research arm of USDA, (Agricultural Research Service), with state and federal agencies cooperating within and among states. Continued advances in the diverse area of forage research will require the same strategy.

The private sector will continue to glean out opportunities where a realistic profit incentive exists, and will provide partial funding to public research for their development. The animal industry does not have a history of funding forage research. Thus, the majority of forage research, such as sustainable farming needs, ecology and the landscape, nutrient management, carbon sequestration, and the environment, will generally lack profit incentives, not fit the industry model, and will need public funding. Basic areas of forage research, including potential uses of biotechnology of forages, will likely also have minimal interests to agribusiness unless a protected market is developed. Yet, all of these areas are critically important to the sustainable use of natural resources and to meet expectations of the American consumer.

Presently, due to lack of public funding, several federal agencies and universities with the land-grant mission are shifting focus from production or nongrant-supported research to research areas that are primarily grant supported. As a result, research programs on forage and grazinglands, which are generally void of direct commodity support, be it political or economic, are being deemphasized. Consequently, significant advances in forage and grazinglands research during the next 50 yr will require increased public appropriations to continue to address critical needs for the good of the country.

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